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PROCESS RESEARCH OF POLYCRYSTALLINE SILICON MATERIAL

(PROPSM)

QUARTERLY REPORT NO. 3

APRIL 1, 1984 THROUGH JUNE 30, 1984

CONTRACT NO. 956698

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(PROPSM)

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The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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I. INTRODUCTION

This report summarizes work performed during the third quarter of an effort that began in November, 1983. The intent of this program is to develop a passivation process (hydrogenation) that will improve the power generation of solar cells fabricated from presently-produced, large-grain, cast polycrystalline silicon (Semix), a potentially low-cost material. The program will consist of two phases. The first objective will be to verify the operation of a DC plasma hydrogenation system and to investigate the effect of hydrogen on the electrical performance of a variety of polycrystalline silicon solar cells. The second objective will be to parameterize and optimize a hydrogenation process for cast polycrystalline silicon, and will include a process sensitivity analysis.

Section II of this report describes the sample preparation for the first phase. Section III summarizes additional results that we have obtained using our hydrogenation system without a plasma.

II. PHASE I SAMPLE PREPARATION

The goal of the first phase of this program as described in the previous report [1] is to establish the basis for performance improvements in polycrystalline silicon solar cells due to the hydrogenation process. Specifically, the question left unresolved by previous studies is whether hydrogenation, as it affects the electrical performance of large-grain cast polycrystalline silicon solar cells, modifies the base, junction, or emitter properties of the devices. However, recent reports, though not conclusive, seem to indicate that hydrogenation is probably a bulk passivant.

As a result of the previous contract, JPL No. 966902, we have developed the capability for fabricating and testing small area photodiodes (so called "mini-cells") on large-area (10cm x 10cm) polycrystalline silicon wafers. We have used this capability, together with dark current-voltage ("dark I-V") junction characterization, to analyze the spatial variation of solar cell electrical characteristics across polycrystalline silicon wafers and have determined that the limiting characteristic is low open-circuit voltage due to excess dislocations located at subgrain boundaries [2,3].

This approach, analyzing small-area photodiodes fabricated on larger area sample substrates, will be utilized in developing

from one another by etching away several microns of silicon from between the cells, resulting in a mesa diode structure.

However, electrical tests of this first set of wafers indicated that significant portions of the n^+ diffused layer were removed from the active area during the mesa etch, thus rendering the wafers unusable. Therefore, fabrication of a second set of mini-cell wafers, from the same ingots, was immediately begun toward the end of the second quarter.

Additional problems delayed the sample fabrication work during this quarter, due to the fact that the process research laboratory at Solarex was shut down for renovation. As equipment was returned to operation, processing resumed, and a portion of the sample set was finished at the end of this quarter. Preliminary testing indicates that this wafer set does not suffer from incomplete emitters and that the cell-to-cell isolation is excellent. Therefore, the remainder of the sample set will be completed, and electrical characterization and hydrogenation will commence.

III. MOLECULAR HYDROGENATION

During the second quarter, we began an experiment to investigate the usefulness of molecular hydrogen annealing on polycrystalline solar cells. Several samples were selected from 4cm^2 solar cells fabricated for the thickness-resistivity matrix of the previous program (JPL Contract No. 955902). The cells were fabricated from 1.5 ohm-cm polycrystalline silicon wafers supplied by Semix, Inc., chemical-polish etched to a thickness of 250 microns, diffused to 70 ohms/square, and alloyed with Englehard A-3484 aluminum paste to compensate the back junction. The metallization system was evaporated Ti-Pd with electroplated Ag. The front contacts were a standard Solarex fine-line chevron pattern, which was photolithographically-defined. The wafers were sintered for 15 seconds at about 475°C before being sawn into 4cm^2 cells, and were sintered an additional 15 seconds after a tantalum oxide anti-reflection (AR) coating was electron-beam evaporated. For this hydrogen annealing experiment, the AR-coating was removed by an HF-vapor etch.

During the second quarter we had attempted to passivate a polycrystalline cell with molecular hydrogen in a manner similar to that described by Amzil, et.al. [4]. The 4cm^2 cell had a low open-circuit voltage (537 mV) and was not shunted (G = 0.07 mmho/cm^2); it was assumed that the voltage loss was due to electrically-active defects that could be passivated. However,

no improvement, even after 20 hours in hydrogen, were realized. Upon further investigation, we noted that the short-circuit current was also low, and that perhaps the low voltage was due to a short minority-carrier diffusion length that was not related to electrically-active grain boundaries. Consequently, for our next trial, we chose samples by the following criteria: (1) low open-circuit voltage; (2) low shunt conductance; and (3) high light-generated current. This criteria should insure that the open-circuit voltage is degraded solely by grain-boundary-related defects.

Two additional 4mc^2 polycrystalline cells (1-10 and 1-14) were chosen for molecular hydrogenation. Their electrical characteristics before hydrogenation are shown in Table 1.

Table 1. Electrical characteristics of two 4cm^2 polycrystalline silicon solar cells before hydrogenation.

CELL NO.	V_{oc} (mV)	J_{sc} (mA/cm^2)	G (mmho/cm^2)
1-10	551	23.5	0.11
1-14	562	25.5	0.10

These cells were hydrogenated in molecular hydrogen (H_2) at a temperature of 300°C for a total time of 1, 2, 5, 10, and 20 hours. Dark I-V characteristics were measured before hydrogenation and after each cycle. The results are shown in Table 2.

Table 2. Dark I-V characteristics of cells 1-10 and 1-14 during molecular hydrogenation.

CELL NO.	CUMULATIVE HYDROGENATION TIME (hours)	J_{QNO}* $\times 10^{-9}$ (mA/cm^2)	J_{sco}** $\times 10^{-3}$ (mA/cm^2)	n-factor
1-10	0	8.4	1.2	2.4
	1	7.9	0.7	2.3
	2	8.4	1.6	2.6
	5	8.4	1.5	2.5
	10	8.1	2.2	2.6
	20	8.8	2.1	2.6
1-14	0	6.3	0.4	2.2
	1	6.8	0.5	2.4
	2	6.8	1.1	2.6
	5	6.5	1.2	2.6
	10	8.5	1.4	2.6
	20	6.6	1.0	2.5

*J_{QNO} = quasi-neutral recombination current density at V=0

**J_{sco} = space-charge recombination current density at V=0

Table 3. Electrical characteristics of two $.4cm^2$ polycrystalline silicon solar cells after 20 hours in molecular hydrogen at 300°C.

CELL NO.	V_{oc} (mV)	J_{sc} (mA/cm^2)	G ($mmho/cm^2$)	V_{oc} (mV)	I_{sc} (mA/cm^2)
1-10	553	24.1	0.09	+2	+0.6
1.14	565	26.0	0.08	+3	+0.5

The differences between the before and after hydrogenation values are so slight as to be negligible. These cells, unlike the previous cells, have light-generated current densities that are indicative of fairly long minority-carrier diffusion lengths. The open-circuit voltage appears to be degraded, and the quasi-neutral recombination current enhanced, by electrically-active grain boundary defects. Therefore, since there is essentially no change in the bulk (quasi-neutral) recombination, we conclude that molecular hydrogen is not useful for passivating electrically-active defects. There was no significant improvement in open-circuit voltage, short-circuit current density, or shunt conductance. Future work will be concerned solely with plasma-based hydrogenation.

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3. J. Culik, "Process Research of Polycrystalline Silicon Material (PROPSM)", JPL Contract No. 956698, Second Quarterly Technical Report, 1984.

4. H. Amzil, M. Sebbar, G. Athian, L. Ammar, and S. Martinuzzi, "Influence of Annealing in Atomic and Molecular Hydrogen on Diffusion Lengths of p-type Polysilicon", 5th E.C. Photovoltaic Solar Energy Conference, 1983.

PROGRAM SCHEDULE

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